DEVELOPMENT OF LIFETIME BRIDGE MANAGEMENT SYSTEM FOR EXPRESSWAY BRIDGES IN JAPAN

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ABSTRACT

These days, proper maintenance and management of deteriorating expressway bridges are becoming serious issues in many countries worldwide. It is necessary to apply proper maintenance actions in order to extend the service life of existing bridges and to minimize their lifetime maintenance & rehabilitation costs. In order to make a proper long-term maintenance strategy, it is necessary to evaluate current condition and predict future deterioration for existing bridge, choose the best maintenance actions at appropriate application times, and determine their expected durations of effect. Under these circumstances, recently privatized Japanese expressway companies have been trying to develop a lifetime bridge management system (BMS) for intercity expressway bridges in Japan. The main objective of this study is to develop a framework for an appropriate lifetime maintenance strategies for deteriorating bridges with emphasis on concrete superstructures.

Recent study revealed that the most relevant mechanisms for deterioration of concrete structures are corrosion of rebar due to chloride induced deterioration or carbonation. Condition evaluation method for bridge elements under several deterioration factors such as chloride induced deterioration and carbonation is introduced using quasi-quantitative grading method. The grading method is based on the results of visual inspection.

One of the most important tools included in the bridge management system is deterioration prediction model. The deterioration prediction curve was calibrated based on the further inspection results and engineers' judgment. Several maintenance scenarios are taken into account in order to compare the life-cycle maintenance cost. An optimum lifetime maintenance strategy for expressway bridges is proposed based on the comparison of present values of expected cumulative maintenance costs.

The proposed bridge management system can be used as a useful tool for decision makers to determine the best maintenance strategy.

KEY WORDS

BMS, expressway bridges, deterioration prediction, lifetime maintenance strategy

1. INTRODUCTION:

These days, proper maintenance and management of deteriorating highway structures are becoming a serious issue in many countries. It is necessary to apply proper maintenance actions to highway bridges in order to extend the lifespan of existing bridges, and minimize the repair and rehabilitation cost. Leading works on BMS in Japan include a study by Miyamoto et al [1]. The research uses the results of regression analysis for statistically processed inspection data and neural network models to evaluate the soundness of concrete beams and slabs using the average soundness for load bearing capacity and durability obtained from the output of an expert system.

Managing infrastructure and rational decision-making is a complex activity requiring both well-experienced engineering knowledge and economical considerations. It is bridge agency's responsibility to ensure bridge structures can cope with the increase in demand without loss of service to the public under the constraints of shrinking budget and lack of experienced maintenance engineers. Right now, intercity expressway systems in Japan are maintained and operated by recently privatized expressway companies from former Japan Highway Public Corporation. One of the three expressway companies, West Nippon Expressway Company Limited (NEXCO-West), is responsible for maintenance and operation of more than 3,000 expressway bridges. These bridges have been in service for 20 years on average. Many of them have been deteriorated due to heavy traffic and severe environmental conditions, and some of them are in need of repair and/or reinforcement. However, so far maintenance actions have primarily been conducted as corrective maintenance, with decisions based mainly on the professional engineering judgment and budgetary restrictions within a short-term basis.

Under these circumstances, Nippon Expressway Research Institute (NEXCO Research Institute) has developed a total bridge management system (NEXCO-BMS) in 2003 in order to support finding the best solutions for lifetime maintenance scenarios for deteriorating expressway bridges.

For most of the decision makers, the most difficult uncertainties associated with actions and decisions were produced by the very absence of data where statistics could be of little help. In order to make better decisions based on life-cycle concepts, better data is required, and the data must be turned into information and put to effective use through advanced decision support. Therefore, the collected data should be shared by everybody involved in the maintenance business in the highway agency so that the decision-making process could be more effective. NEXCO has developed integrated maintenance database such as inventory data, inspection records and repair/reinforcement history for over 3,000 bridges. That database could be of great help to predict future conditions of bridges by calibrating deterioration prediction curve created by mathematical equations.

In general, deterioration of highway structures progresses at an increasing rate with time. Therefore, total life-cycle cost could be reduced by applying preventive maintenance in early stage of deterioration than postponing it until the deficiencies become evident. This is because deterioration of bridges accelerates year by year [2].

Currently, the importance of performing preventive maintenance actions in order to reduce the life-cycle cost and achieve a longer service life has been widely recognized. However, in reality, it is difficult to allocate the limited budget to preventive maintenance actions due to the shortage of budget and accumulating backlogs of essential maintenances. In addition to it, a strategy of preventive maintenance may be more difficult to justify because the public's expectation is that the worst roads demand immediate attention. Furthermore, the public often interprets activities related to preventive maintenance actions as "fixing something that isn't broken" [3]. Life-cycle cost analysis (LCCA) is an effective tool in order to prove the cost-effectiveness and return on investment of such a preventive strategy relative to traditional strategies. LCCA is an evaluation technique applicable to the consideration of certain transportation investment decisions [3]. Specifically, when it has been decided that a project will be implemented, LCCA will assist in determining the best (the lowest-cost) way to accomplish the project. The LCCA approach enables the total cost comparison of the competing maintenance alternatives, each of which appropriate for implementation.

In order to perform LCCA, it is important to develop a system that can express the present condition of structures, the effects of various maintenance actions, and the prediction of future conditions.

The main objective of this study is to develop a framework for determining the best maintenance scenario for expressway bridges with emphasis on concrete superstructures. Based on the prediction of future condition states for expressway bridges, various kinds of maintenance actions are applied depending on the condition states. The distribution of the first application time of each maintenance action is determined based on the condition transition time calculated by the deterioration prediction model. To find the lifetime maintenance cost for each maintenance scenario, Monte Carlo simulation was performed with the sample numbers of 10,000. Both zero and non-zero discount rates are used to help understanding the effect of time value of money on results.

The optimum lifetime maintenance strategy for highway bridges should be determined based on the comparison of present values of expected cumulative maintenance costs under different maintenance scenarios. It is concluded that the preventive maintenance option is the most cost effective maintenance scenario. In addition, iterative application of preventive maintenance can guarantee the better condition states compared to the corrective maintenance options in which maintenance actions are not applied until the onset of corrosion in rebar. The proposed framework can be useful for decision makers to determine the best maintenance strategy.

2. CONDITION EVALUATION

2.1 Definition of condition state

There are several methods to evaluate the condition state of a concrete structure. It is desirable that the assessment of various performances of a structure be conducted using quantitative indicators such as chloride ion content in the concrete, carbonation depth, or corrosion of steel rebar. However, in practice, obtaining all quantitative data for all structures is not economically efficient. Therefore, in most BMSs the condition states are verbally described and the quasi-quantitative grading method is widely applied to the evaluation of concrete structures.

This quasi-quantitative grading method is used also in NEXCO-BMS, since the visual inspection results are recorded based upon the discrete condition states. General definition of each condition state in NEXCO-BMS is defined as shown in Table 1 [4]. Each grading is related to a possible maintenance strategy such as preventive maintenance, corrective maintenance with repair or rehabilitation. State V represents the critical condition that means failure of an element. Fig. 1 graphically shows the visual appearance of RC deck slab in State I to V in the inspection manual [5].

Table 1 General definition of grading in NEXCO-BMS [4]

Condition State	Definition	Maintenance strategy
I	Good condition	Do nothing
II	Fair condition	Preventive Maintenance
III	Poor condition	Corrective Maintenance (Repair or Rehabilitation)
IV	Serious condition	Corrective Maintenance (Rehabilitation)
V	Critical Condition	Failure

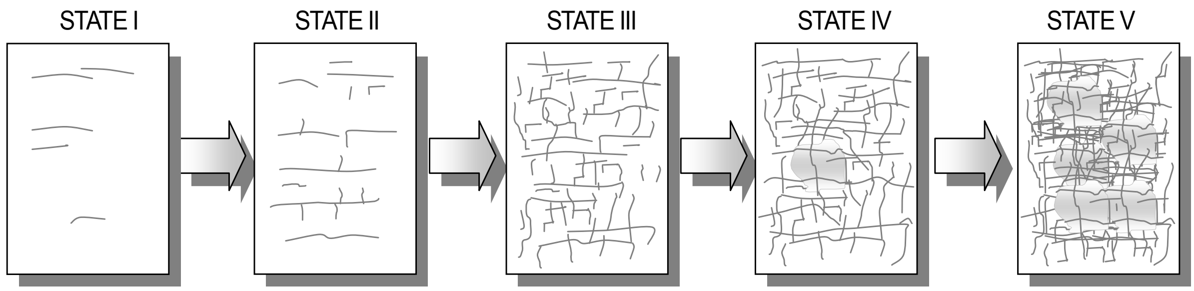

Fig. 1 Visual appearance of RC deck slab in State I to V [5]

2.2 Grading criteria for chloride induced deterioration

Table 2 shows the grading criteria of the severity of deterioration for structures affected by chloride induced deterioration [6].

The commonly used grading of apparent defects related to the progress of deterioration are “initiation”, “propagation”, “acceleration”, and “deterioration stages” [7]. In the grading method shown in Table 2, states I and II correspond to the “initiation stage”, the stage up to the time when the chloride ions content at the position of rebar reaches the threshold value (i.e., 1.2kg/m^3), and state III corresponds to the “propagation stage” that is from the initiation of steel corrosion to the propagation of corrosion cracks at the concrete surface. State IV corresponds to the “acceleration stage” that is the period during which corrosion is accelerated by corrosion cracking. State V corresponds to the “deterioration stage”.

In this method, two kinds of indicators are used to provide the quantitative criteria of grading. The first indicator is chloride ion content X [kg/m^3] at the position of rebar. When the chloride ion content becomes greater than $1.2kg/m^3$, steel rebar becomes vulnerable to corrosion, and the structure is classified as state III, where the corrosion of the rebar begins to cause cracks in concrete. From this stage, the indicator representing the characteristics of the deterioration will shift to the corrosion of rebar Y [%]. When the value of Y becomes greater than 10%, the structure will be in its final stage of deterioration (i.e., state V). This threshold value of Y came from the fact that 10% reduction of rebar cross-section means the failure of members because the bond between steel rebar and concrete would be disappeared [8].

Table 2 Grading criteria [Chloride induced deterioration] [6]

Condition State	Definition	Quantitative Threshold Values
I	No visual appearance of deterioration	$0 \leq X < 0.8$
II	No visual appearance of deterioration	$0.8 \leq X < 1.2$
III	Cracks and rust exudation	$1.2 \leq X$, $0 \leq Y < 5$
IV	Many cracks and rust exudation Spalling and falling of the concrete fragments	$5 \leq Y < 10$
V	Many cracks with large width. Rust exudation, Spalling and falling of the concrete Large displacement and deflection	$10 \leq Y$

X = Chloride ion content at the position of rebar [kg/m^3]
Y = Corrosion of rebar [%], defined as (Corroded area / Total area of rebar) ·100)

3. PREDICTION OF FUTURE DETERIORATION

The prediction of future performance degradation and remaining service life of a bridge member is one of the most important topics for all bridge management systems. The future condition of structural members under chloride induced deterioration can be predicted using two kinds of indicators: chloride ion content in the concrete at the position of rebar and corroded area of rebar. During the initial period, (i.e., states I and II in Table 2) when the diffusion depth of the chloride ion is the dominant factor of deterioration, chloride ion diffusion can be predicted using the Fick's second law of diffusion as shown in eq. (1). The approximate solution of eq. (1) is shown in eq. (2) [7].

$$\frac{\partial C(x,t)}{\partial t} = D\left(\frac{\partial^2 C(x,t)}{\partial x^2}\right) \tag{1}$$

$$C(x,t) = C_0\left(1 - erf\frac{x}{2\sqrt{D\cdot t}}\right) + C(x,0) \tag{2}$$

where
$C(x, t)$ = Chloride ion content at the depth of x (cm) and at time t (years) (kg/m^3)
C_0 = Chloride ion content on the concrete surface (kg/m^3)
D = Apparent diffusion coefficient of chloride ions ($cm^2/year$)
erf = error function
$C(x, 0)$ = Chloride ion content at the depth of x (cm) and at time 0 (year) (kg/m^3)

As the deterioration of a structural member progresses into state III (see Table 3), corrosion of rebar would start and it becomes the dominant indicator of deterioration instead of chloride ion content. Corrosion of rebar can be predicted by eq. (3) [9]:

$$Y = \frac{3.8\times10^{-3}}{\phi}\times e^{0.15t} \tag{3}$$

where
Y = Corrosion of rebar (%) at time t (years)
t = Elapsed time after the chloride ion content reached $1.2kg/m^3$ at position of steel rebar

ϕ = diameter of the steel rebar (cm).

In general, most of the decisions during maintenance and management of bridge structures shall be made under conditions of uncertainty. In this sense, bridge performance, its remaining life, and expected lifetime maintenance cost can be predicted only in terms of a probabilistic way. Uncertainty is naturally associated with random phenomena because the exact realization of a phenomenon cannot be determined with certainty [10]. The conceivable or possible realizations may be described in terms of a range of possibilities, with their respective relative likelihoods of occurrence (e.g., with a probability density function). In other words, if the state of nature is basically random, it cannot be described with a deterministic model; its description must include a measure of its inherent variability and thus uncertainty. For practical purposes, the required description may have to be limited to the main descriptors of interest, which are the central value (e.g., the mean or median) and its measure of dispersion (e.g., standard deviation or coefficient of variation). Available observational data are normally used to estimate the central value and the degree of dispersion of the possible realizations.
The probabilistic approach to predict the deterioration of bridge elements is most commonly carried out by Markov chain method used in PONTIS BMS [11]. Current condition states of bridge elements are investigated and Markov transition probabilities between different condition states are used to evaluate and predict future performance of deteriorating structures. However, currently predominant Markov based management systems cannot address the environmental and material properties of each structure because they are not based on the physical behavior of the deteriorating structures.
In the deterioration prediction model described in this paper, eqs. (2) and (3) are used to perform a probabilistic prediction of future deterioration for concrete bridges under chloride induced deterioration. As mentioned previously, the corrosion of steel begins when the chloride concentration reaches the critical value. Many experimental studies on existing bridges showed that the concentration level of chloride ion at the position of rebar varies in a very broad range. For instance, the cracking due to shrinkage and/or tensile loading condition affects the overall permeability of the concrete member and the distribution of the chloride concentration with respect to time. In addition, perfect control of water-cement ratio is very difficult in practice, mainly due to the fact that course aggregate and fine aggregate contain certain amount of water and the moisture contents of aggregates vary with time, depending on the temperature and the relative humidity of the environment [12]. Therefore, most of the influencing variables exhibit significant randomness. The effect of uncertainties associated with the influencing variables on chloride penetration increase as the life span of a structural system increases [13].
Therefore, in this paper, the randomness of most variables is taken into account, and a probabilistic prediction of deterioration for concrete bridges is performed based on eqs. (2) and (3). For problems involving random variables with known (or assumed) probability distributions, Monte Carlo simulation is required to predict the future events [1]. This involves repeating a simulation process, using in each simulation a particular set of values of the random variables generated in accordance with the corresponding probability distributions. By repeating the process, a sample of solutions, each corresponding to a different set of values of the random variables, is obtained. A sample from a Monte Carlo simulation is similar to a sample of experimental observations.
In this study, the Monte Carlo simulation method is used efficiently to evaluate the effect of propagation of uncertainties on the distributions of these parameters. Based on the simulation results on distributions of X and Y, the probability of transition of condition states can be predicted.
The input parameters used in the prediction of future condition states are tabulated in Table 3. All random variables are assumed to have lognormal distribution. Each random variable is characterized by its mean value μ, and standard deviation σ. Numbers in parentheses in Table 3 represent mean values and standard deviations associated with lognormal distribution.
Calculating the time required for the chloride ion content to up-cross a given threshold level in Table 2 gives the time required for the condition state of the structure to transit to the next condition state. The probability of the event P [$X(t) \geq X_{CRITICAL}$] can be evaluated by Monte Carlo simulation as follows:

$$P[X(t) \geq X_{CRITICAL}] \cong \frac{m}{M} \quad (4)$$

where: m and M are the number of samples satisfying the condition $X(t) \geq X_{CRITICAL}$ and sample size of the simulation, respectively. The probability of (4) is computed at specific points in time. The period of staying in state I and II (i.e., before the onset of corrosion) can last for many years depending on the corrosion resistance of the steel, the thickness and quality of concrete cover, and other corrosion protection measures applied to the structure [12].
Similarly, probability of corrosion of rebar to up-cross a given threshold level can be computed in the

same manner.

Table 3 Stochastic input parameters for chloride induced deterioration [14]

Input parameters	Probabilistic Values
Water cement Ratio *W/C*	LN (50%, 5%)
Initial chloride content *C(x,0)* (kg/m^3)	0.0
Chloride ion content on the concrete surface C_0 (kg/m^3)	LN (2.0, 0.2)
Thickness of cover concrete H_{COVER} (cm)	LN (3.5, 0.35)
Diameter of steel rebar ϕcm)	LN (1.6, 0.016)
Critical chloride concentration $X_{CRITICAL}$ (kg/m^3)	LN (1.2, 0.12)

LN (μ, σ) = Lognormal Distribution (mean, standard deviation)

Fig. 2 shows the result of Monte Carlo simulation for chloride ion content at the position of rebar with respect to time. Based on these values, corrosion of rebar will occur around *t* = 20 years in average. Fig. 3 shows the result of Monte Carlo simulation for corrosion of rebar with respect to time. Relatively large standard deviation in corrosion of rebar *Y* is attributed to the large scatter in corrosion initiation time. Table 4 shows the probability of being in each condition state with respect to time. The bridge agency that owns a group of bridges wants to know when the first bridges are eligible for repair, in order to allocate sufficient funds. Therefore, finding the distribution of the transition time of condition states can be useful information. If a bridge owner is responsible for a group of structures whose material performance and environmental conditions are similar to one another, the information shown in Table 4 can be used to predict the number of bridges that need to be repaired or rehabilitated at a given point in time.

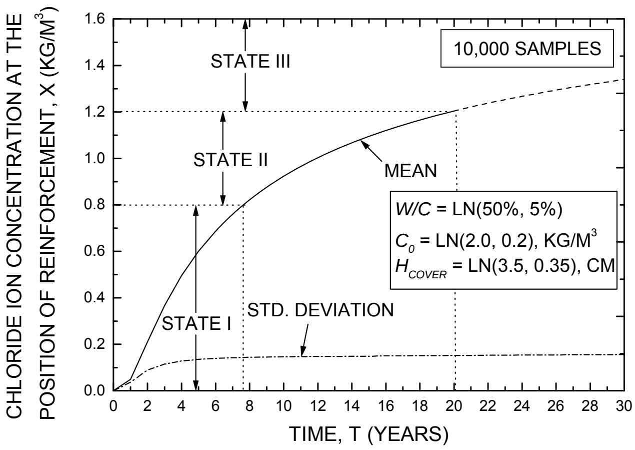

Fig. 2 Main descriptors of chloride ion content at the position of rebar

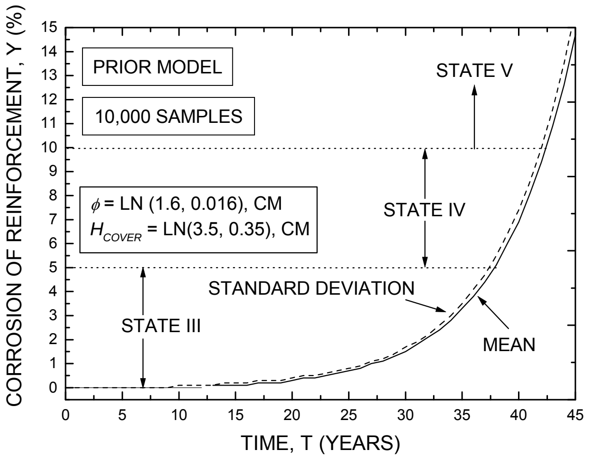

Fig. 3 Main descriptors of corrosion of rebar (Chloride induced deterioration)

Table 4 Probability of being in each state (Chloride induced deterioration)

Time, *t* (Yrs)	State I (%)	State II (%)	State III (%)	State IV (%)	State V (%)
0	100.0	0.0	0.0	0.0	0.0
10	23.4	69.4	7.1	0.0	0.0
20	0.7	48.8	50.5	0.0	0.0
30	0.1	23.8	72.0	4.2	0.1
35	0.1	17.1	59.4	16.9	6.7
40	0.0	12.8	40.8	18.5	27.8
50	0.0	7.8	17.7	9.2	65.3
60	0.0	5.4	8.2	3.8	82.7
70	0.0	3.8	4.5	1.7	90.1
80	0.0	2.8	2.7	0.7	93.8

4. OPTIMUM MAINTENANCE STRATEGY

In this section, probabilistic approach to determine the optimum maintenance strategy for structures under chloride induced deterioration is discussed. Maintenance actions shown in Table 5 are considered. In Table 5, the target condition state, duration of effect, and unit cost of each maintenance action is summarized. Each maintenance action will be applied when the condition state of the structure violates the target condition state. Duration of effect is the time during which the effect of maintenance action is valid. At the end of this time period, the same maintenance action will be applied again to the structure. Lining A and lining B will be applied when the condition state violates the target condition state (i.e., state II). Therefore, these two options can be classified as preventive maintenance. Desalination and major concrete repair can be classified as corrective maintenance actions, because they are applied after the onset of corrosion in rebar. Rebuild is an option doing nothing until the condition state of the structure is degraded to state V. The cost of rebuild includes failure cost and user cost for the inconvenience during the reconstruction work.

Based on the assumptions noted above, distribution of cumulative maintenance cost for each maintenance scenario is calculated using 10,000 samples of Monte Carlo simulation. Both zero and non-zero discount rates, (i.e., 0.0% and 6.0%) are considered in this study. As an example, a bridge slab with concrete surface of 1,000m^2 was considered. The cost of each maintenance action can be

calculated by multiplying the cost per unit area shown in Table 5 by 1,000m^2.
Fig. 4 shows the mean values of cumulative maintenance costs under different maintenance scenarios at discount rate of v = 0.0%. As can be seen in Fig. 4, it is obvious that rebuild option has significantly higher mean cumulative cost compared to the other maintenance options. Preventive maintenance options are more economical compared to the corrective maintenances and rebuild option. However, this is not true at the beginning of lifetime. The transition time happens usually after t = 20 to 30 years. The comparison of the two corrective maintenance actions, i.e., desalination and major concrete repair reveals that mean cumulative cost for desalination is much higher than that for the major concrete repair. Therefore, applying major concrete repair can be a better corrective maintenance option provided that there is enough space under the bridge for the execution of major concrete repair. Two preventive maintenance options, i.e., lining A and lining B, show almost the same mean cumulative cost which are much less than those of corrective maintenance options or rebuild option. Comparing the cumulative maintenance cost for these two preventive maintenance scenarios reveals that lining A has a little bit lower maintenance cost than lining B. These results indicate that frequently applying maintenance actions with lower unit cost gives the lower lifetime maintenance cost.
Fig. 5 shows the mean values of cumulative maintenance costs under different maintenance scenarios at discount rate of v = 6.0%. The mean cumulative cost for rebuild and desalination are still much higher than the other maintenance options. However, mean cumulative cost for major concrete repair has become closer to those of the preventive maintenance options due to the discounting effect. Generally, the later the probability distribution of maintenance application time, the larger its cost is discounted. Therefore, the discounting effect is more beneficial to corrective maintenance or rebuild options than it is to preventive maintenance options because of their later application times. However, relatively small unit costs of preventive maintenance actions counteract this effect. Until t = 40 to 45 years, mean cumulative cost for major concrete repair is lower than the preventive maintenance options. However, at the end of the time horizon (i.e., t = 80 years), it will be 50% greater than that of lining A, and 30% greater than that of lining B.
This information can be used in developing maintenance strategies and evaluating lifetime maintenance cost in order to appropriately allocate the limited funds. It can be concluded from these figures that applying lining A is the scenario that gives the minimum lifetime maintenance cost. In addition, this preventive maintenance scenario can also guarantee that the condition state of the structure is always better than state II. Therefore, the maintenance scenario applying lining A when the condition state violates its target condition state (i.e., state II) is the most attractive maintenance scenario both from the viewpoint of minimizing the lifetime maintenance cost and keeping the bridge structure in a good condition. Highway agencies can use these recommendations as decision support in determining its maintenance strategy.

Table 5 Applicable maintenance actions for chloride induced deterioration [14]

Maintenance Action	Target Condition State	Threshold Value	Duration of effect (years)	Cost (Unit/m^2)
Lining A	II	$X \geq X_{CRITICAL}$ (I-II)	LN (10, 1.0)	5.0
Lining B	II	$X \geq X_{CRITICAL}$ (I-II)	LN (15, 1.5)	7.5
Desalination	III	$X \geq X_{CRITICAL}$ (II-III)	LN (20, 2.0)	70.0
Major concrete repair	IV	$Y \geq 5\%$	LN (30, 3.0)	100.0
Rebuild	V	$Y \geq 10\%$	LN (50, 5.0)	700.0

LN (μ, σ): Lognormal distribution (Mean, Standard deviation)

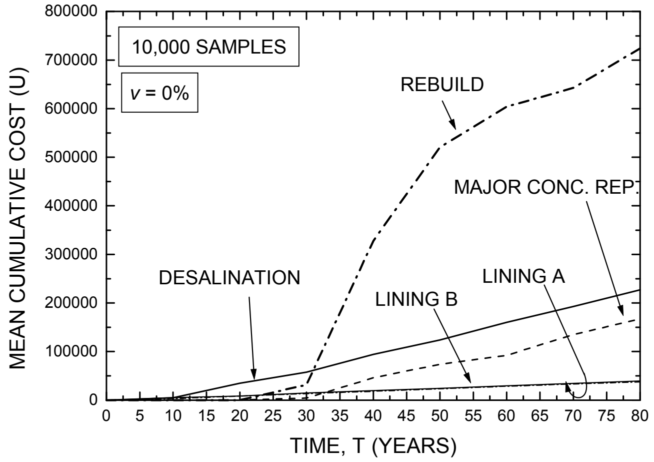

Fig. 4 Mean cumulative cost under different maintenance scenarios (v = 0.0%)

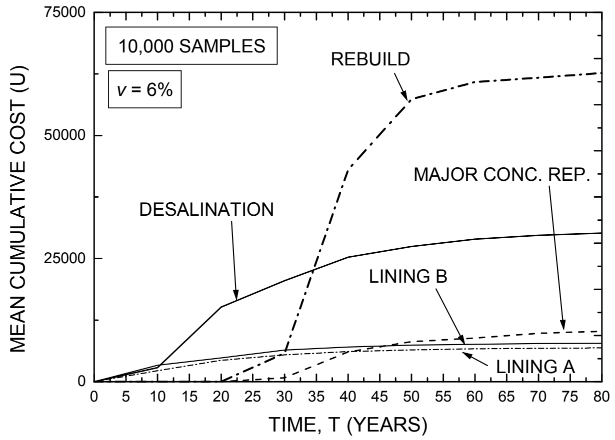

Fig. 5 Mean of cumulative cost under different maintenance scenarios (v = 6.0%)

5. CALIBRATION OF DETERIORATION PREDICTION

Deterioration prediction should be calibrated by mainly visual inspections and detailed investigations. In this study, two kind of calibration method are applied;

(1) Calibration by environmental conditions

Future deterioration often varies from the local characteristics such as chloride quantity, especially under severe environmental conditions. Based on investigation of actual bridges, chloride ion content on the concrete surface (C_0 in eq. (2)) varies from not only distance from coast but also from local characteristics. The investigation results revealed that C_0 value for the actual bridges along the Sea of Japan was almost the same as those calculated by eq. (2), whereas bridges along the other side of Japan (the Pacific Ocean) has lower C_0 values (see Fig. 6). The results of the investigation should be use for calibration of given equation [15].

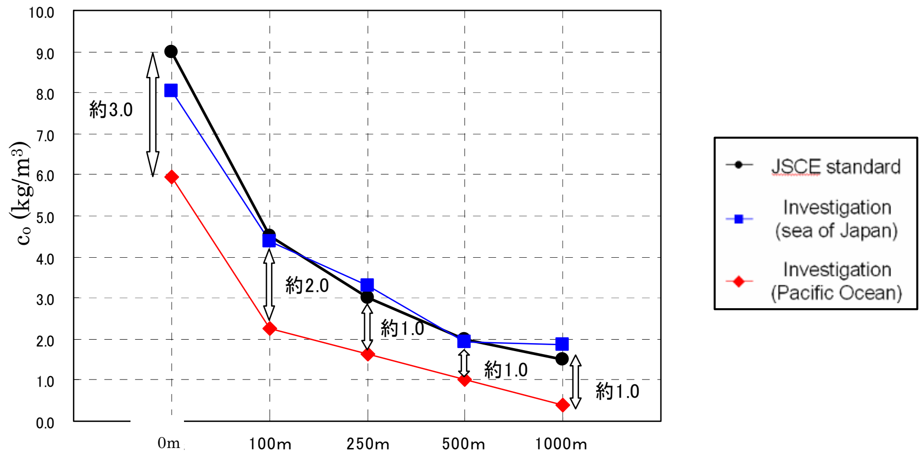

Fig. 6 Relationship between C_0 and distance from coast [16]

(2) Calibration based on visual inspection
When more historical inspection data has been obtained, calibration of deterioration prediction can be conducted depending on the deterioration mechanism and environmental conditions (see Fig. 7). This can help increase the reliability of deterioration prediction.

Deterioration mechanism: Chloride induced deterioration

Member: Concrete slab

Environmental conditions: less than 1km from coast

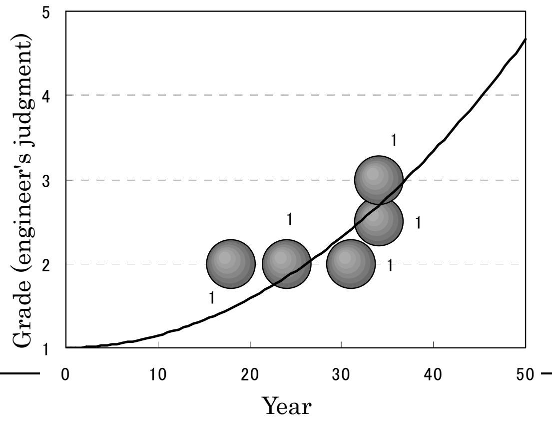

Fig. 7 An example of regression analysis for deterioration prediction [15]

6. SUMMARY AND CONCLUSION

1. The current issue regarding the maintenance of expressway bridges was overviewed.

2. A probabilistic approach to predict the future condition states of the structure was discussed. Monte Carlo simulation method is used efficiently to evaluate the effect of propagation of uncertainties on the future condition states of the structures.

3. A methodology to determine the optimum maintenance strategies were discussed based on the comparison of cumulative lifetime maintenance cost under different maintenance scenarios.

4. From the present value of the expected cumulative maintenance cost under different maintenance scenario, it is concluded that the preventive maintenance strategy applying lining A is the most cost effective maintenance scenario both in the case study for chloride induced deterioration and carbonation. In addition, iterative application of preventive maintenance can also guarantee the better condition states compared to the corrective maintenance options in which maintenance actions are not applied until the onset of the corrosion in rebar.

5. The results obtained in this study illustrates that the most attractive maintenance scenario could be

the one which frequently applying the preventive maintenance action with lowest unit cost before it is too late. This kind of analysis can be of great help to prove that the preventive maintenance scenario actions could be a better option than corrective maintenance actions to minimize the expected cumulative life-cycle cost.
This conclusion is in good agreements with those demonstrated by Frangopol et al. [17] and Kong and Frangopol [13].

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